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14. ABSTRACT
Over the duration of phase I of the ISP (01-Aug-2002 to 31-Jul-2005), we built two digitally controlled sensing sytems and assembled a tabletop environment for testing and demonstration of massive date acquisition and handling. Components of the system are discussed. A variety of analytical tools for achieving the diffusion and low-dimensional paramaterizations have been developed. Examples given of results during the research in phase 1, and details of the research are provided in the two appendices.

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ISP phase I achievement and progress.
Award Period: 01-Aug-2002 to 31-Jul-2005
Final Report

Date: 3 January 2006

Performer: Yale University

Contract #: F49620-02-1-0314
Title: "Integrated Sensing and Processing Digital Synapses"
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Executive Summary:

In phase I of the Yale/Plain Sight Systems project we have concentrated on dynamic sensing and processing for hyperspectral imaging.

- We built two digitally controlled (using digital mirror array MOEMS) sensing systems for direct manipulation of light streams in both passive and active sensing modes.

- In the active mode we assembled a tabletop environment for testing and demonstration of massive data acquisition and handling. Virtually all aspects of the ISP concept can be emulated in this environment, where imaging is done through a microscope, dermascope, or endoscope.

To be specific the components of the system consist of

- A digitally controlled spectrally tunable light source capable of generating any desired spectral profile of light in the range of 400-900 nm. The light spectrum can be encoded by pseudo random code to optimize SNR. The light can be tuned to reveal specific targets and suppress clutter in a complex environment. The tuning of the light is integrated in real time with detection and identification tasks.

- The data acquisition test platform is a microscope on which the scenes and targets consist of histology microdot slides of hundreds of tissue samples. The tuned light source is used as the microscope light source, to allow acquisition of

full hyperspectral datacubes. A similar platform was built for direct monitoring of skin lesions using a dermascope.

- As an example of interactive sensing and processing in this environment, we start with the expert (pathologist) pointing out a few cancer cells (in a small region). These are "diffused mathematically" to other very similar spectral or spatio/spectral objects in the scene. The expert points out obvious failures, and this knowledge introduces new features to refine the process by looking for new spectro/spatial features .

The light is then tuned so that each measurement by a pixel of the camera measures directly a spectral feature of the tissue at that location. If, for example, we display the top three features in, say, RGB, the potential cancer cells are highlighted in the other portion of the scenes (the rest of the slide or other slides).

This can be realized at video rates, since we only measure information of interest (and not a whole spectrum). The conventional mode here would be to collect the whole spectral cube, digitize, extract features and display. Here we are only measuring directly information prior to digitization, avoiding the raw data glut.

- A variety of analytical tools for achieving the diffusion, as well as low dimensional parameterizations of geometric structures in the hyper spectral data have been developed. These tools enable quantification of data features probability density estimation, detection of outliers and many other signal processing tasks on line .

The advantage of tissue data is that it is as varied as any landscape, with targets which are elusive and abstract, for which conventional template matching techniques fail. We were forced to develop nonlinear variants of principal components analysis to help in the dimensional reduction information extraction tasks. These methods which involve a blend of diffusion theory, spectral theory, geometry and harmonic analysis, have also been validated in the context of characterization of inertial manifolds for nonlinear dynamics where the data is generated by dynamical systems and the inertial manifolds are obtained empirically from computer experiments leading to identification and explicit parameterization of relevant observables.

- In the process described above we are using active interrogation of the target with specifically designed light so that the interaction with the material and the light will reveal information concerning the target.

- We have also considered the dual problem in which the data acquisition is passive but the light streams are digitally controlled before sensing.

- We have built a coded aperture spectral imaging camera. The purpose of the camera is to detect and reveal camouflaged objects, anomalies in clutter, chemical signatures etc.

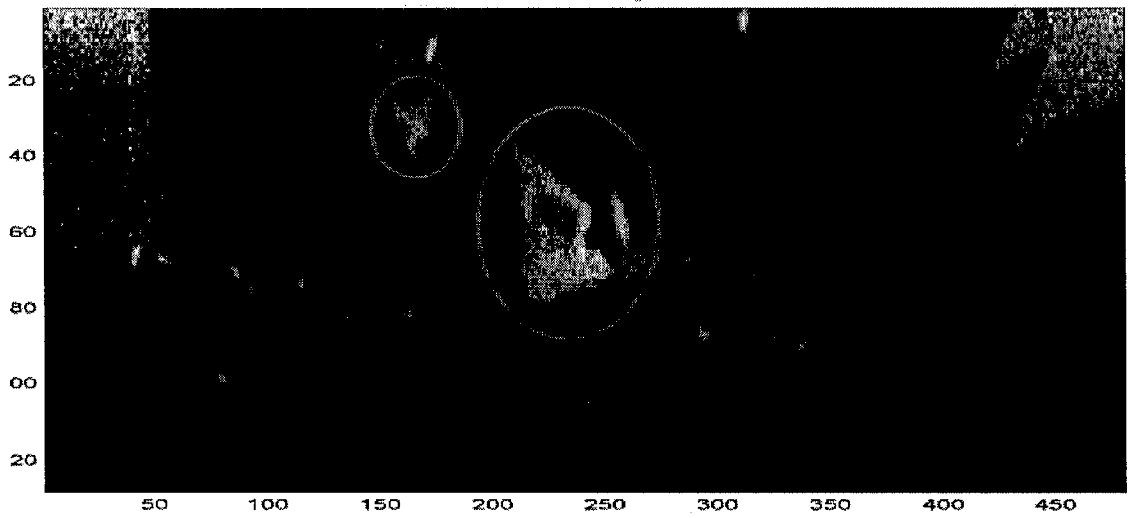
By imaging first on a digital mirror array, prior to spectral separation, the camera controls both the spatial region whose spectral features are measured as well as the corresponding combination of spectral features. This system is not as versatile as the active system but opens interesting possibilities if combined with digitally tunable CMOS imaging arrays.

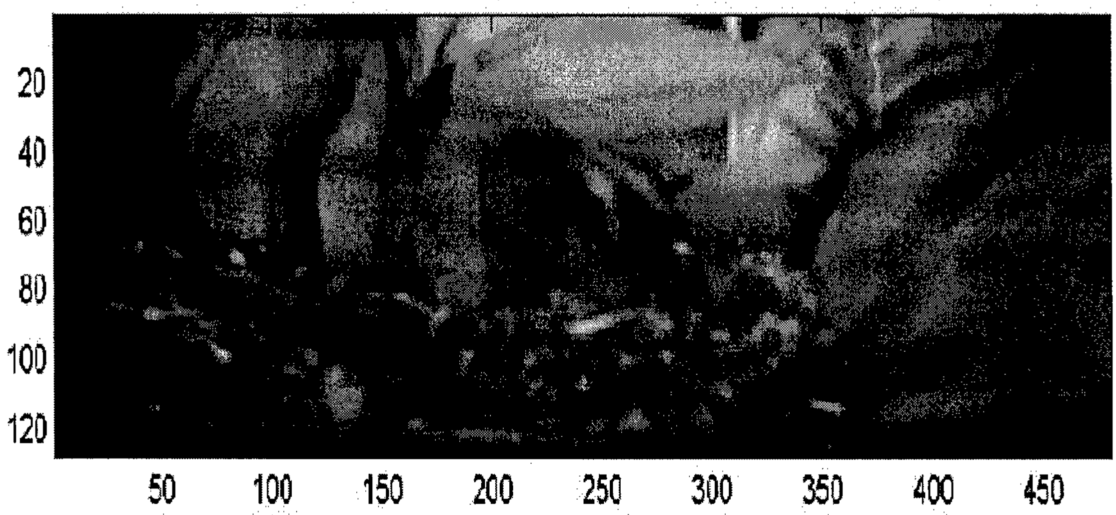
- The camera described above has been redesigned in the Near Infra Red, as a prototype for field testing by Lockheed Martin. This will enable evaluation of various algorithmic and driving tradeoffs in operational situations.

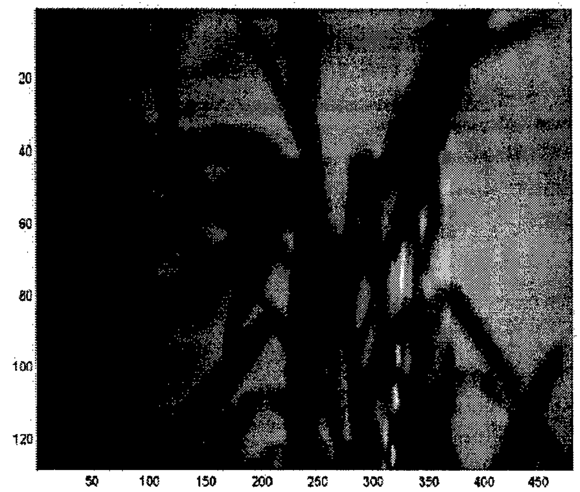
We provide a few examples of the ideas described above, and details are provided in the appended documents.

The process of tuning the spectral acquisition to detect a target is illustrated in the following images, where the target in the first image is extracted by measuring directly the residual spectral energy over the majority average clutter spectrum , and the displayed in rgb.

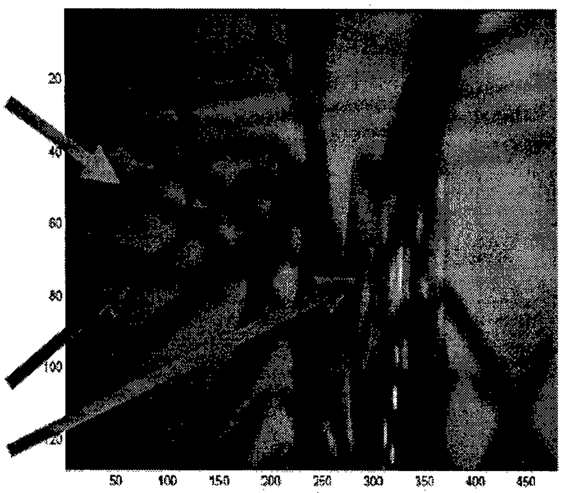
Filtered Image

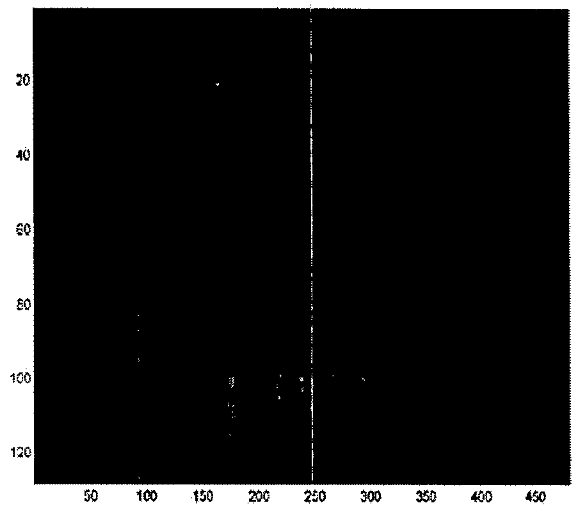




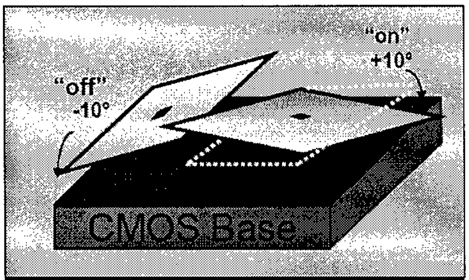


Fake vegetation is discovered easily through the standoff coded aperture imager, Bottom right; a conventional spectrograph image under same light integration setting.



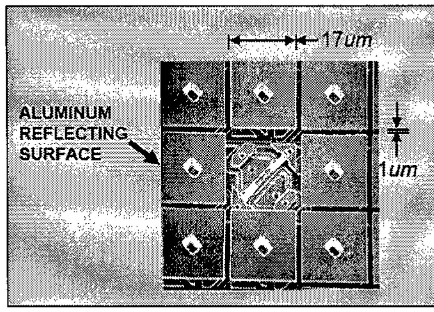


The control of the light spectra, either on acquisition or in active mode for probing is achieved using a TI Digital mirror array described below. By directing light rays onto a grating we control the amount of light going through the system in any frequency band.

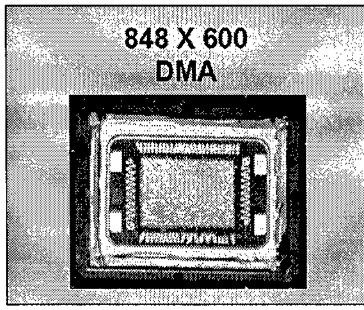


Mirrors rotate along their diagonal axis by exactly ± 10°, which is what makes the DMA a digital devise

- **0 = no light reflected (-10°)**
- **1 = all light reflected (+10°)**

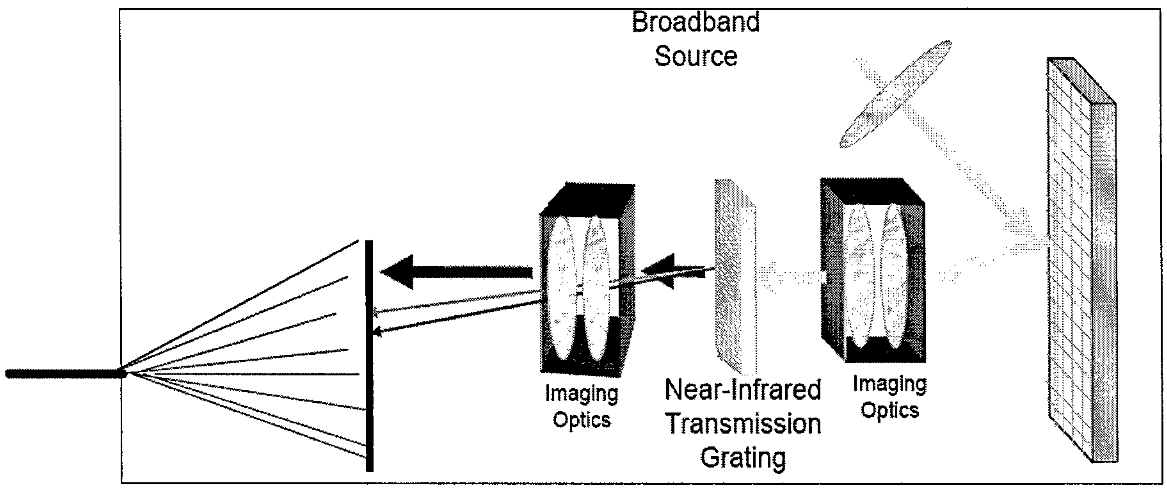


Mirrors are built on top of integrated circuits and assembled in a grid-like formation



A complete DMA contains 848 columns and 600 rows of mirrors and measures 10.2 mm x 13.6 mm. Here, a DMA is shown with its glass cover removed.

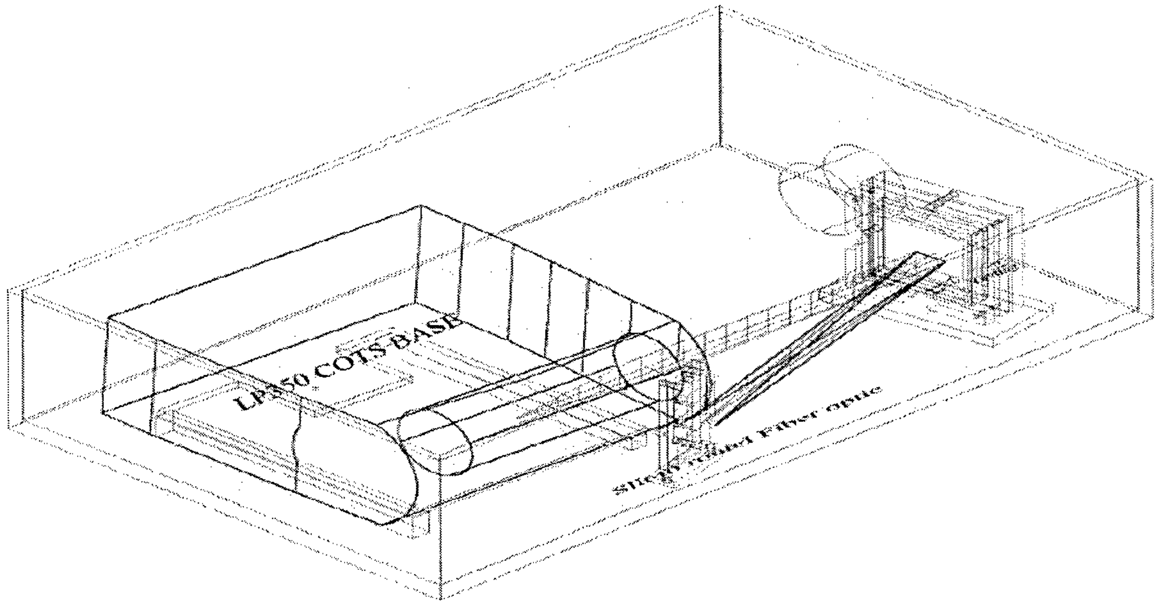
Digitally tuned light source



Fiber optic slit

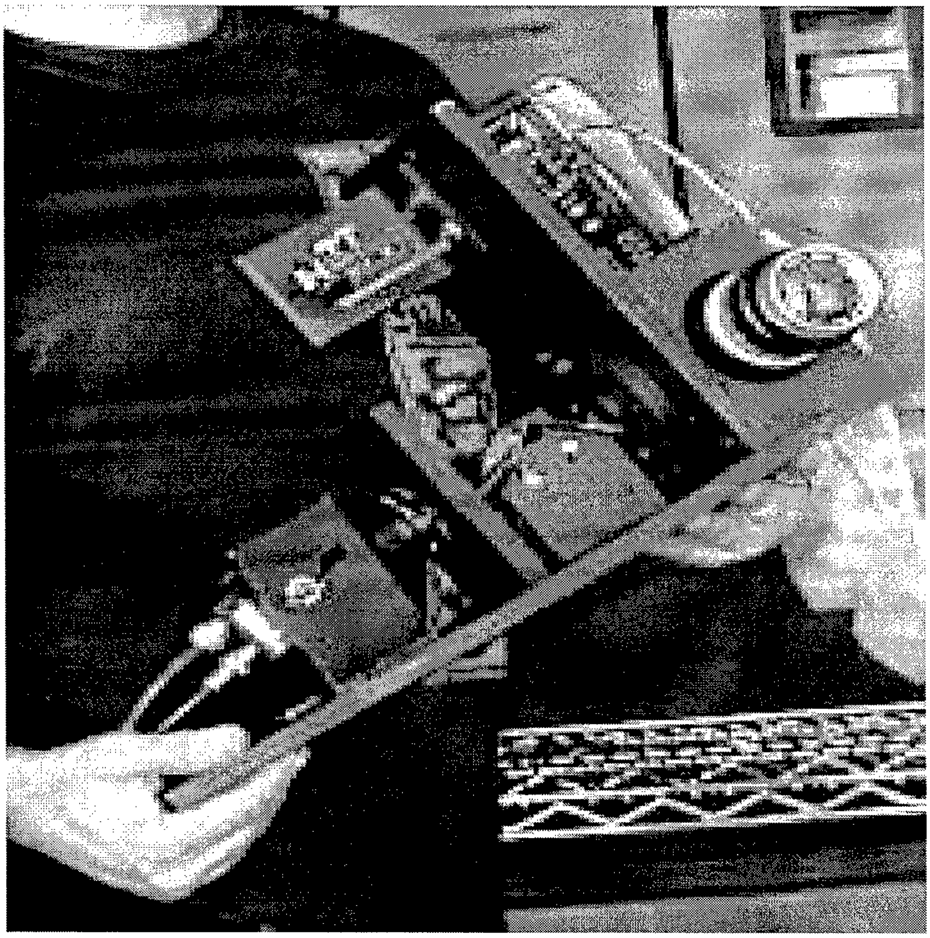
DMA
mixer

New instrumentation

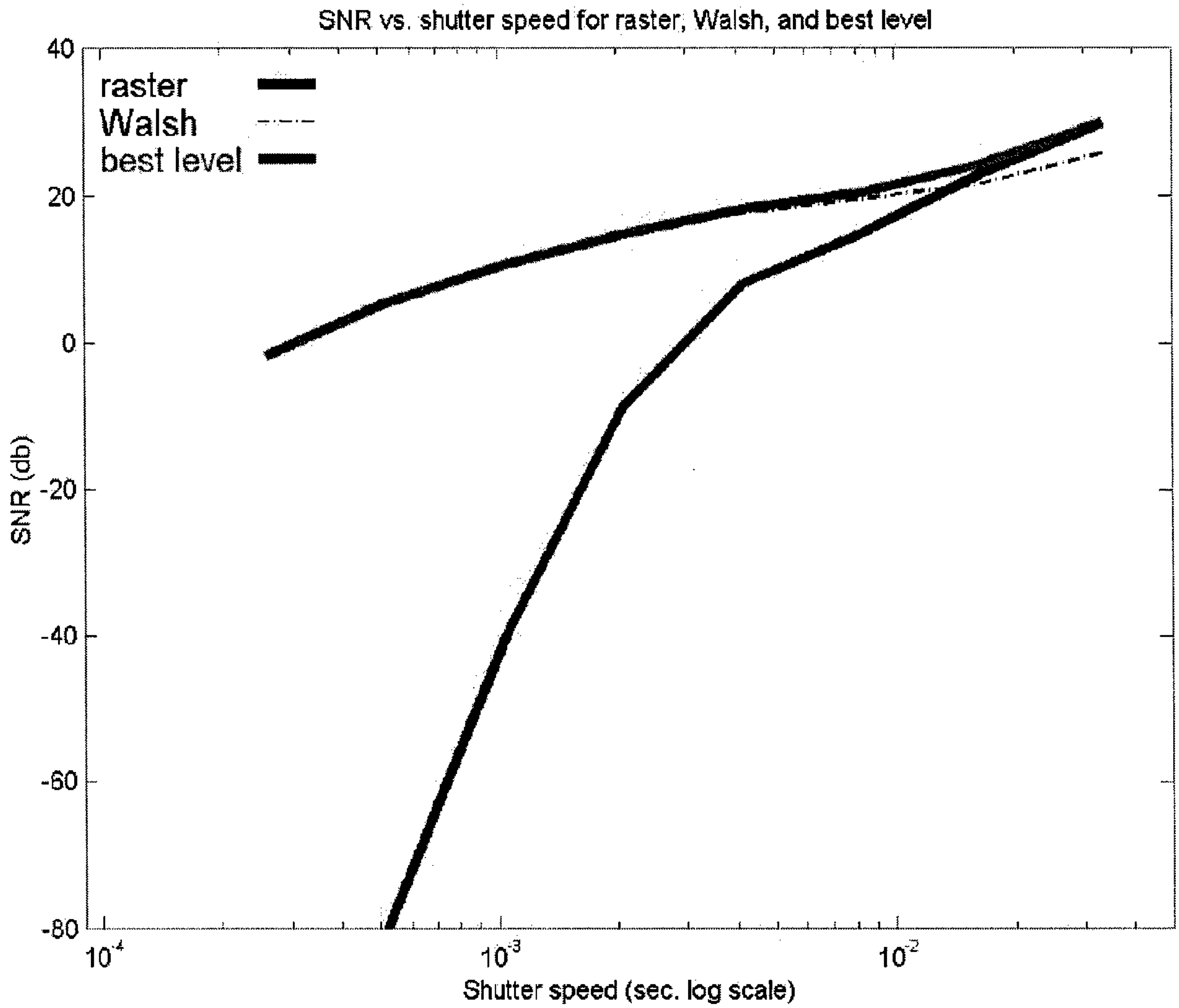


A digitally controlled tuned light source can be used as a spectrometer and/or direct chemometric analysis system. By tuning the illumination spectrum to interact with the absorption response of material in the scene ,we can directly measure the presence of specific objects.

We have also developed a passive DMD based system which produced the results on camouflaged objects described above .



For this system we have demonstrated that by using pseudo random encoding of the spectral acquisition process we enable a superior performance of the camera, and that in particular we should be able to collect spectral data at video rates ,while collection in a conventional raster mode fails.



The hardware devices above have been extensively tested
A software hyperspectral explorer tool kit has been
developed as an algorithm exploration tool box .
(See appendix A)